[title]Scientific Studies of the High-Latitude Ionosphere with the Ionosphere Dynamics and Electrodynamics-Data Assimilation (IDED-DA) Model
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[bestaccomplishment] With only ground magnetometer measurements, our high-latitude data assimilation model can track the formation and evolution of propagating plasma patches in the polar region, and these plasma patches are known to be a source of scintillations that can affect DoD operations and systems.
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Scientific Studies of the High-Latitude Ionosphere with the Ionosphere Dynamics and ElectroDynamics - Data Assimilation (IDED-DA) Model

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LONG-TERM GOALS

The goal of the project is to conduct scientific studies to elucidate the momentum and energy processes that play a significant role in magnetosphere-ionosphere coupling at high latitudes, with the emphasis on mesoscale (~ 100 km) plasma phenomena.

OBJECTIVES

We will conduct simulations with a high-latitude data assimilation model. The specific objectives are to study magnetosphere-ionosphere (M-I) coupling processes for: (1) super storms, pulsating storms, and substorm, (2) different seasons and solar activity levels, (3) relatively smooth and highly structured convection and precipitation scenarios, and (4) both northward and southward Interplanetary Magnetic Field (IMF) configurations.

APPROACH

Our approach is to use our Ionosphere Dynamics and ElectroDynamics - Data Assimilation (IDED-DA) model to accomplish the goal and objectives outlined above. Our IDED-DA model is a physics-based, ensemble Kalman filter model of the high-latitude ionosphere and electrodynamics that can account for rapid time variations of the order of minutes and spatial scales less than 100 km (*Schunk et al., 2006; Zhu et al., 2012*). The IDED-Data Assimilation model is based on three physics-based models, including a magnetosphere-ionosphere (M-I) electrodynamics model, an ionosphere model, and a magnetic inversion code. The ionosphere model is a high-resolution version of the Ionosphere Forecast Model (IFM), which is a 3-D, multi-ion model of the ionosphere that covers the altitude range from 90-1500 km (*Schunk, 1988; Sojka, 1989; Schunk et al., 1997*). The main electrodynamics inputs to the IFM are the plasma convection and precipitation patterns, which are obtained from the M-I electrodynamics model. The IFM calculates global distributions for plasma densities (N_e, NO^+, O_2^+, N_2^+, O^+, H^+), temperatures, and velocities. The M-I electrodynamics model is a high-resolution (10 km), time-dependent (5 sec) model of M-I coupling at high latitudes (*Zhu et al., 1993, 2000, 2005*). The model is based on a numerical solution of the MHD transport equations and Ohm's Law, with height-integrated Hall and Pedersen conductivities obtained from the IFM. The model calculates currents and electric fields. The magnetic inversion code takes a 3-D current system as an input and

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calculates the associated **ΔB** in space and on the ground. The three physics-based models are used with an ensemble Kalman Filter to assimilate SuperDARN radar velocities, in situ velocities from the DMSP satellites, and **ΔB** from both ground and satellite magnetometers. The output of the IDED-DA model is a full set of self-consistent, time-dependent plasma and electrodynamics parameters for the high-latitude regions, including Electric Potential, Convection Electric Field, Energy Flux and Average Energy of Precipitation, Field-Aligned and Horizontal Currents, Hall and Pedersen Conductances, Joule Heating Rates, 3-D Electron and Ion Densities, 3-D Plasma Drifts, 3-D Electron and Ion Temperatures, Total Electron Content (TEC), and Ground and Space Magnetic Disturbances **(ΔB).**

WORK COMPLETED

(1) Previously, we conducted IDED-DA simulations with measurements from 40 – 60 ground magnetometers and ACE satellite data. In the course of these studies, we discovered three 'new' physical features: (1) A field-aligned current along the solar terminator due to the conductivity gradient, (2) The break-up of a stable tongue-of-ionization into plasma patches in the polar cap during a northward IMF excursion, and (3) A plasma tongue-of-ionization the originates from the 1800 local time sector. During the last year, two scientific papers have been submitted for publication describing our initial findings; one on the terminator current and the other on the tongue-of-ionization.

(2) A poster, entitled 'Terminator field-aligned current system: A new finding from model-assimilated data set (MADS)' by L. Zhu, R. W. Schunk, L. Scherliess, J. J. Sojka, L. C. Gardner, J. V. Eccles, and D. Rice was presented at the 2013 Fall Meeting of the American Geophysical Union, December 8-14, 2013, San Francisco, California.

(3) Data from ground magnetometers in the northern hemisphere and from the DMSP satellites have been collected for additional data assimilation studies pertaining to quiet and storm conditions, and to changes of the Interplanetary Magnetic Field (IMF). The data cover different seasonal and solar cycle conditions.

(4) Additional IDED-DA simulations have been conducted in order to study the behavior of the three new physical features for different solar cycle, seasonal, and magnetic activity conditions. Two papers are currently being written describing our latest results.

RESULTS

Our first paper describing the field-aligned current system that is aligned with the terminator is listed below, and in the following we show one of the cases where the terminator current appeared. The IDED-DA simulation was for days 351-352 of 2000, which was a magnetically quiet period. For this case, data from 40 ground magnetometers in the northern polar region were assimilated in the IDED-DA model. The distribution of the magnetometers was such as to provide less than 1° resolution in latitude. Data were assimilated with a 1-minute time step. The required solar wind and IMF data were obtained from the ACE satellite. On day 351, the terminator field-aligned current first appeared at around 1900 UT, then gradually increased in intensity, and eventually disappeared at around 2300 UT. The current was spatially collocated with the ionospheric terminator all the time during the period. On the second day (day 352), the terminator field-aligned current appeared two times. The first appearance started at around 1130 UT and the second was around 2100 UT, and for both cases the terminator current remained there for about 3 hours.

Figure 1 shows a snapshot of the ionospheric environment when the terminator field-aligned current reached its peak intensity. The top two panels show NmF2 and NmE on a log scale and the bottom two panels show the convection electric potential and field-aligned current. The blue color in the field-aligned current plot shows the upward field-aligned current. A careful comparison of the top panels and the field-aligned current plot indicates that the location of the terminator field-aligned current was actually at the nightside edge of the ionospheric terminator. The peak intensity of the terminator field-aligned current was around 0.4 $\mu A/m^2$, which was larger than that of the region 1 upward field-aligned currents in the auroral oval at that time. The figure also shows that the terminator field-aligned current was a simple upward current system and there was no paired field-aligned current structure. This means that the current closure of the terminator field-aligned current was through the horizontal ionospheric current over a large region and there was no localized return current associated with it.

In another IDED-DA study, we simulated the northern high-latitude region for December 17, 2001, which contained a long period of southward IMF followed by a northward IMF excursion (Eccles et al., 2014). Data from 89 ground magnetometers were assimilated at a 5-minute time step, and the ACE satellite provided the required solar wind and IMF parameters. On this day, a 2-cell plasma convection pattern remained stable for several hours, and this resulted in a stable tongue-of-ionization that extended across the polar cap from the sunlit noon sector toward midnight. However, the IMF turned northward at about 1700 UT, which resulted in a convection disruption. This, in turn, caused the tongue-of-ionization to break up into plasma patches in the polar cap. A similar result was also seen in the IDED-DA simulation of day 352 in 2000 (Figure 2). Polar cap patches are typically associated with severe scintillations, which affect several DoD systems and operations.

IMPACT/APPLICATIONS

Numerous countries have become interested in the Arctic because of the melting of the ice and the gas and oil reserves that have become accessible. Hence, this region is now a focus of the DoD. In the future, the IDED-DA model will be able to provide ionosphere specifications and forecasts for the polar region. These specifications and forecasts will be useful for DoD command and control operations, including scintillation identification, HF communication links, over-the-horizon (OTH) radars, surveillance, and navigation systems that use GPS signals.

RELATED PROJECTS

None

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Zhu, L., R. W. Schunk, V. Eccles, L. Scherliess, J. J. Sojka, and L. Gardner, Terminator field-aligned currents: A new finding from the Ionospheric Dynamics and Electrodynamics Data Assimilation Model, *J. Geophys. Res., 119,* doi:10.1002/2013JA019518, 2014, (refereed).

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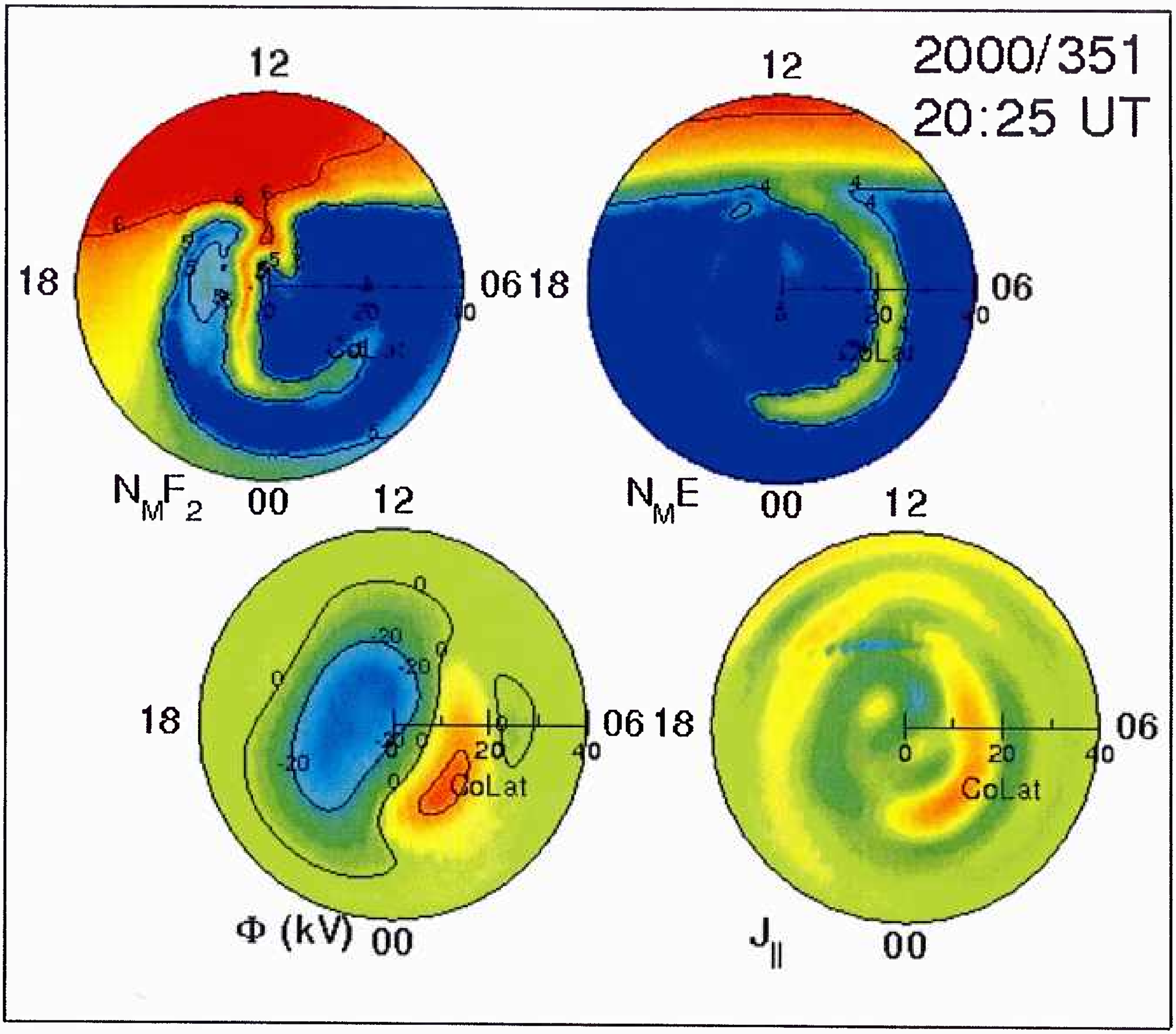

Figure 1. Distributions of NmF2, NmE, convection electric potential, and field-aligned current at 2025 UT, day 351, 2000 (Zhu et al., 2013).

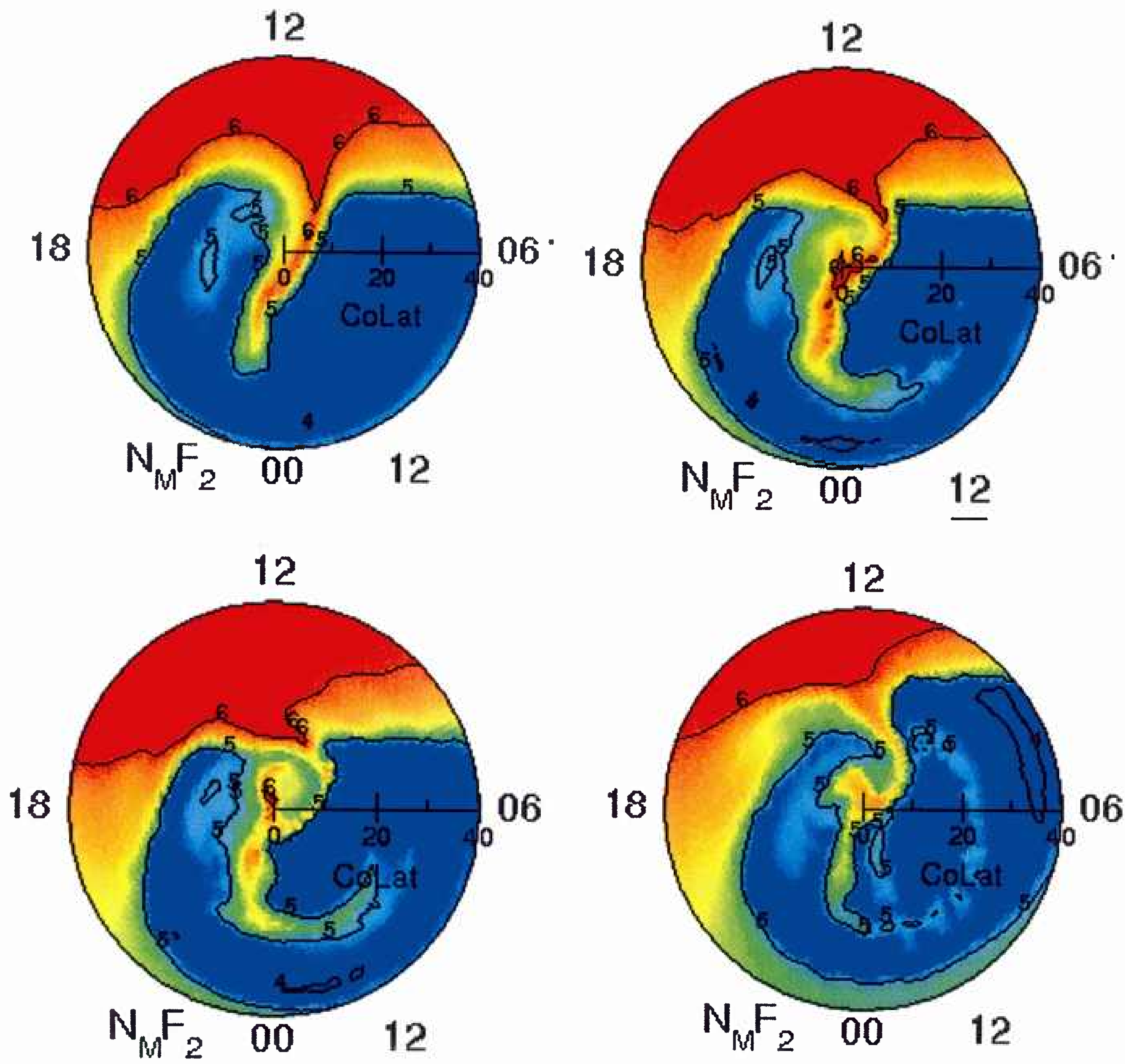

Figure 2. Snapshots of NmF2 in the northern polar region from an IDED-DA simulation of day 352, 2000. The times are 15:00 UT (top left), 17:40 UT (top right), 18:40 UT (bottom left), and 23:40 UT (bottom right).